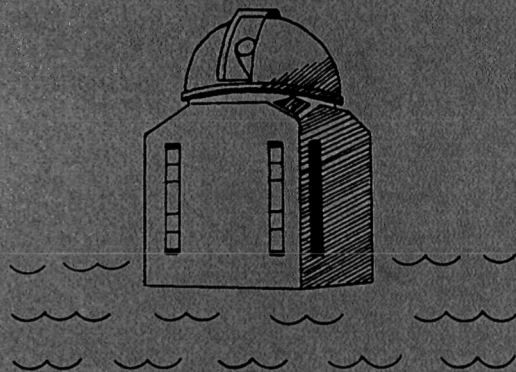CALIFORNIA INSTITUTE OF TECHNOLOGY

BIG BEAR SOLAR OBSERVATORY

DYNAMIC SIGNATURES OF QUIET SUN
MAGNETIC FIELDS

S. F. Martin

BBSO #0228

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ABSTRACT

The motions of network fragments, ephemeral regions, and intra-network structures result in the frequent interaction of their magnetic fields. The merging of similar polarity magnetic fields from any of these sources occurs without obvious net change in the magnetic flux. However, when opposite polarity magnetic fields from any source collide, mutual loss of magnetic flux is observed to take place gradually in the colliding fields until the smaller magnetic field fragment completely disappears. Colliding magnetic fields of opposite polarity were always observed to have spatially separate origins; evidence of the submergence of an ephemeral region or any original bipole has not been seen.

The collision and disappearance of opposite polarity fields is observed most frequently at the borders of network cells. Due to observational limitations, the frequency, magnitude, and spatial distribution of magnetic flux loss have not yet been quantitatively determined at the borders or within the interiors of the cells. However, in agreement with published hypotheses of other authors, the disappearance of magnetic flux is speculated to be a consequence of either gradual or rapid magnetic reconnection which could be the means of converting magnetic energy into the kinetic, thermal, and nonthermal sources of energy for microflares, spicules, the solar wind, and the heating of the solar corona.

1.0 INTRODUCTION

Three categories of quiet sun magnetic fields are currently recognized: network magnetic fields, ephemeral active regions, and intra-network magnetic fields. A few basic characteristics of each of these types of magnetic fields are briefly reviewed in the first paragraph of sections 3, 4, and 5 respectively. The references provide the starting point for the first objective of this paper, to illustrate new aspects of the dynamic character of the network, ephemeral regions, and intra-network magnetic fields. The second objective is to present new observational data showing interactions between these three types of magnetic fields.

2.0 OBSERVATIONAL TECHNIQUES

Magnetograms of the line-of-sight component of solar magnetic fields are made daily with the videomagnetograph at the Big Bear Solar Observatory, time-sharing the beam of a 25 cm refracting telescope with two other birefringent filters and photographic cameras. The prime image is enlarged sufficiently to place a field of view between 3 X 4 and 6 X 8 arc minutes on frames of 35 mm film.

The original videomagnetograph has been described in detail by Smithson and Leighton (1971) and Smithson (1972). The videomagnetograph now employs a 1/4 $\overset{\circ}{A}$ passband birefringent filter on the CaII spectrum line at 6103 $\overset{\circ}{A}$. The filter is preceded by a KDP crystal to which high voltage is applied in synchronization with the 1/30 sec scan time of a television camera recording the images. The KDP crystal, in combination with the filter, alternately passes and rejects the circularly polarized light from opposite polarity magnetic fields on the sun. An image processor is used to digitize, add, and operate on selected numbers of scans from the television camera to produce the videomagnetograms. The final magnetograms may be stored permanently in digital form on magnetic tape and/or displayed on a television monitor and photographed on 35 mm film.

The magnetograms illustrated in this paper were selected from time-lapse films of videomagnetograms that had been successively displayed in real time on the television monitor. The shortest exposure for a single videomagnetogram, containing both polarities of magnetic field, is 1/15 second. However, to visually see the magnetic signal of most solar features, many successive 1/15 second magnetograms must be integrated over time using the image processor. Figure 1 illustrates the changing appearance of an area of the quiet sun on 28 June 1983 as the number of integrations is increased by powers of 2 from 2^7 to 2^{10} (128 to 1024) integrations. We have learned empirically that 2^7 to 2^8 (128-512) integrations of successive 1/15 second scans are required to bring out most of the magnetic network on the quiet sun. Numerous ephemeral active regions can be seen with 2^9 to 2^{10} (512-1024) integrations. 2^{10} (1024) integrations or more are required to visually see the intra-network (intra-supergranule) magnetic fields.

3.0 MOTIONS OF THE MAGNETIC NETWORK

The magnetic network is the residual magnetic fields of decayed active regions which are dispersed in irregular fragments around the boundaries of the supergranules (Simon and Leighton 1964). It is known to diffuse continuously over increasingly large areas of the sun, and is most clearly evident in the global studies of solar magnetic fields (see review by Howard 1978). Smithson (1972) found small scale discrete motions in which fragments of field appear to break away from larger clumps of network. Martin and Harvey (1976) noted that these discrete motions occurred along the boundaries of the network cells. The merging as well as the splitting of network fragments has been reported by Komle (1979).

Because our recent videomagnetograms have higher sensitivity than those studied by Smithson (1972), it is now possible to observe and measure these discrete motions of splitting and merging fragments of network. Examples of these discrete motions of network fragments are shown in Figure 2 in an area of mostly negative polarity (black) network. The open ended polygon labelled

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S1 in the middle of Figure 2 encloses a network fragment that is splitting off from a larger fragment. The pointed end of the polygon shows the direction of motion, which appears to be along the boundary of a fairly well-defined network cell. The relative speed of the migrating element from its source is .16 +/-.05 km/sec. There is no evidence of acceleration or deceleration during the hours of measurable motion, from 1941 to 0048 UT beginning on 1983 August 31. The acceleration expected, at least at the start of the relative motion, is not observed because the motion begins before the fragment is resolved as a separate piece of network. A second clear example of the relative motion of a separating network fragment is labelled S2 in the upper right of Figure 2. The speed of S2 is .20 +/- .05 km/sec.

The coalescence of network fragments is also frequently observed. Two examples, identified as J1 and J2 in the upper left corner of Figure 2, are enclosed in the open-ended rectangles. The motion is in the direction of the open end, approximately parallel to the sides of the rectangles. The open end locates the network fragment towards which the other fragment is moving. The motion of coalescence is similar in magnitude to the motion of the splitting fragments. The motion of the smaller fragment towards the larger fragment, considered to be stationary, is .28 +/- .05 km/sec for J1 and .12 +/- .05 km/sec for J2. In the long exposure videomagnetograms, the network fragments which either split from or coalesce with other fragments are all small, less than 5 arc seconds in apparent diameter. This size does not represent the true size of the magnetic field structures but rather the spatial resolution of the long exposure magnetograms which varies from about 2 to 5 arc seconds depending upon atmospheric image quality and the accuracy of the telescope guiding during the exposure. The fragments that are larger than about 5 arc seconds do not appear to have these relatively rapid discrete motions. However, this is probably only due to saturation of the recorded magnetic field at our relatively long exposures. All fragments that appear to be larger than this are also composed of fine structure which is verified generally in magnetograms of shorter exposure and also in CaII filtergrams. In this paper, we discuss only the motions seen in the weaker network fragments that are best seen in the long exposure videomagnetograms.

The discrete motions of the network fragments seem to occur more frequently around new supergranules than fully developed supergranules. The increased motion makes possible the identification of new supergranule cells. In the lower left corner of each frame of Figure 2, a relatively new supergranule is seen to approximately double its size during the observing day. The approximate center of the cell is marked C1. Below C1, an arrow denotes the site of the birth of a new network cell, C2, assumed to outline a new supergranule cell. The development of these young cells becomes obvious in the videomagnetograms because of the discrete motions of the network fragments along the cell boundaries as the cells grow. In Figure 2, the sites where discrete motion is seen in the time-lapse videomagnetogram film are marked with arrows near the cell boundaries in the direction of apparent motion of the fragments. In many of the magnetograms, including some of those selected for Figure 2, the network cells are further defined by weak magnetic field along the cell boundaries between the fragments of stronger magnetic field.

4.0   MOTIONS OF EPHEMERAL ACTIVE REGIONS DURING GROWTH AND DECAY

Ephemeral active regions are readily differentiated from network magnetic fields because of their bipolar character, evolution, and relatively brief lifetimes (Harvey and Martin 1973; Harvey et al. 1975). Small areas of opposite polarity mixed in network field of a given polarity such as noted by Bappu et al. (1968) are now generally recognized to be the short-lived halves of ephemeral regions. Harvey and Martin (1973) observed, on magnetograms obtained at Kitt Peak, that ephemeral regions originate as closely spaced bipoles whose opposite polarities separate as function of time as the ephemeral regions gain in magnetic flux, similar to the behavior of active regions in general. The rates of relative separation of opposite polarities found by Harvey and Martin were up to 5 km/sec. In the Big Bear videomagnetograms for 1983, similar rates of motion are seen.

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Examples of the typical growth pattern of ephemeral regions are shown in Figure 3. Four ephemeral regions are enclosed in ovals labelled E1, E2, E3, and E4. All of these ephemeral regions are increasing in magnetic flux relative to most of the network magnetic fields. The four ephemeral regions in Figure 3 have all reached their maximum magnetic flux by 1955 UT, and E2 has noticeably decayed. It can be seen in Figure 3 that the ephemeral regions have reached or passed their maximum magnetic flux when a gap begins to appear between the negative and positive components as they steadily separate from each other. The gap between opposite polarities of an ephemeral region is gray, indicating an absence of a net line-of-site magnetic field. The absence of a gap does not mean that an ephemeral region is still growing, because the separation of opposite polarities can be inhibited when ephemeral regions are born very close to network magnetic fields or other ephemeral regions. For example, note in Figure 3 that E3 forms between stronger adjacent magnetic fields and shows less separation than E1, E2, and E4. In Figure 4 other examples are shown. Note that ephemeral regions E6 and E7, which develop on or very near the boundaries of a well defined network cell, separate very little as a function of time, in contrast to E5, which forms close to the center of a network cell and shows a relatively rapid separation of its opposite polarities. E5 is among the smallest ephemeral regions identified to date.

In Figures 3 and 4, ephemeral regions E1-E7 also illustrate the absence of any obvious preferential location of ephemeral regions at birth relative to the network. These ephemeral regions also show the lack of a preferential orientation at birth either with respect to solar latitude and longitude or to the network cell boundaries, confirming the conclusion of Harvey and Martin (1973). The orientation of active regions or ephemeral regions can be defined by the direction of a line drawn from the centroid of the negative polarity to the centroid of the positive polarity. Using this definition, E6 is initially oriented perpendicular to the boundary of the network cell, while E7 is aligned approximately parallel with the boundary of the network cell. The initial orientation sometimes changes as an ephemeral region grows.

Due to both the motion of separation of ephemeral regions and their absence of any preferential orientation relative to the network, it should be expected that random mergers and collisions should occur between adjacent ephemeral regions or between ephemeral regions and network fragments. The demise of one polarity of an ephemeral region with opposite polarity field was noted by Komle (1979) and previously by Martin and Harvey (1976). It is further known that very small flares are observed when ephemeral regions occur very close to network fragments (Marsh 1978).

In the long exposure magnetogram movies, ephemeral regions and network fragments frequently are observed on apparent collision courses and their magnetic fields frequently appear to come into contact. Magnetic fields of similar polarity appear to merge without any other obvious concurrent changes in the videomagnetograms, other than a local enhancement of the field at the site of merging. The collision of opposite polarity fields, on the other hand, results in the dramatic disappearance of magnetic field as illustrated in Figures 5 and 6. We assume that equal amounts of opposite polarity magnetic field disappear although sometimes, due to saturation of the magnetic field on the magnetograms, it is only obvious that the smaller fragment of field is disappearing.

The disappearance of magnetic flux is illustrated in Figures 5 and 6. In Figure 5, a small negative polarity field fragment, F1, splits into two, with the fragment to the left (west) appearing to move at a rate of .45 km/sec relative to the remainder of the original fragment, which stays approximately stationary with respect to the majority of other network fragments in the field of view. Positive polarity fragment F2 is moving south at a rate of .24 km/sec and at an angle of 62 degrees with respect to the path of F1. Between 1750 and 1800 UT the two opposite polarity fragments appear to come into contact as exposed for 512 integrations (31 sec). By 1900 UT, both fragments are noticeably reduced in total flux relative to other network fragments in the field of view. By the end of the observing day, 2247 UT, the positive polarity fragment has disappeared and the negative polarity fragment has nearly disappeared.

Abrupt changes in the motion of both fragments F1 and F2 occur at about the same time that the fragments appear to come into contact. The measurements reveal no further motion after 1800 for the slower moving positive polarity fragment; the negative polarity fragment thereafter has an average reduced speed of .23 km, half of its previous speed.

When the motion of magnetic field fragments is observed over short distances, one often cannot readily distinguish between curvilinear motion and rectilinear motion. However, some magnetic field fragments reveal distinct motion along curved paths. An example is the positive polarity fragment, F3, labelled on frame 16 18 03 in Figure 5. Early in the day F3 was observed to separate from the positive polarity clump of magnetic field to the north of it. Initially F3 was moving in a relatively straight southerly path and passed by negative polarity fragment, F4, with no apparent interaction. When F3 was a few arc seconds southeast of F4, around 20 hours UT, it turned sharply to the east, and subsequently slightly northward, proceeding in the direction of negative fragment, F5. The observing day ended too soon to verify whether the anticipated collision between F3 and F5 occurred.

Another variation in the examples of colliding fragments of opposite polarity is shown in the upper right of Figure 5. Negative field fragment, F6, and positive field fragment, F7, slowly move closer to each other and appear to come into contact by 17 04 12. Thereafter both fragments appear to decrease in flux. However, their relative motion does not cease upon apparent contact. Instead, they slide past each other, giving the illusion of a rotating bipole. The net apparent rotation after contact is seen to be approximately 90 degrees. By 22 24 52, the negative fragment has disappeared.

A clear example of interaction between an ephemeral region and opposite polarity network is in the upper left of Figure 6. Ephemeral region E8 shows the usual separation of its opposite polarities. However, it is oriented such that the positive pole is moving towards a clump of negative network. Loss of magnetic flux, at least in the positive polarity fragment, has begun by 19 03 11, coincident with the positive pole appearing to come into contact with the network. By 21 37 35 or before, this fragment is no longer visible.

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Ephemeral regions can also lose flux in the decaying stage without any obvious magnetic interaction with adjacent magnetic fields. An example is ephemeral region E9 in Figure 6. From the beginning of the observations on 1983 July 2 a widening gap between the poles of E9 is seen. Concurrently, the magnetic flux in both polarities is slowly disappearing. We can be certain of the real decrease in flux since the overall quality of the magnetograms is increasing. The ephemeral region has completely disappeared before either pole has migrated sufficiently close to nearby network fields where potential merger or annihilation could have been expected.

In areas where the density of the network exceeds the density of ephemeral region production, annihilation or recombination with network magnetic fields or other ephemeral regions is probably the most common way in which about half of the ephemeral region flux is lost. The remaining half of the flux probably joins the network of similar polarity, thereby replacing the flux lost in the network from recombination with the opposite polarity flux of ephemeral regions. Thus the occurrence of ephemeral regions and their interaction with each other and the network represents a continuous process of gain and loss of magnetic fields. Over long intervals of time, a primary effect of the interaction of ephemeral regions with the network should be an apparent diffusion of the network fields as discussed by Marsh (1978). The network, therefore, is not just the residual magnetic fields of large active regions but also the residual fields of all active regions including ephemeral regions.

Adjacency or apparent contact of opposite polarity fragments alone is not a requisite condition for interaction of opposite polarity fields. In the center of the images in Figure 6, positive field fragment F8 is observed adjacent to negative polarity network. F8 is stationary and unchanging until 19 05 11. F9 during this time is moving west toward F8. The origin of F8 and F9 is unknown, although F8 is likely to be half of an ephemeral region and initially unrelated to F9. This statement is based on our experience in analyzing our quiet sun observations to date. Of all the ephemeral regions observed from birth in the videomagnetograms, none have been seen to reverse the normal separation of opposite polarities. Thus, there is also no evidence.

for submergence of initial bipoles. A conspicuous decrease in flux occurs between 19 03 11 and 21 37 35, coincident with the negative polarity fragment F9 coming into contact with positive field fragment F8. By 22 25 51, F8 has disappeared and F9 is appreciably reduced in total magnetic flux. There is no apparent change in flux in the negative network clump which remained adjacent to F8 before and after the interaction of F8 and F9.

5.0 INTRA-NETWORK MAGNETIC FIELDS

Intra-network magnetic fields have been described from high resolution magnetograms from Kitt Peak National Observatory obtained under conditions of very good atmospheric image quality. Livingston and Harvey (1975) found a mixture of both polarities and some bipolar grouping (see also Harvey 1977). Additionally, the magnetic features were seen to exhibit motion from the cell interior towards the cell boundaries which was often nonradial (Harvey, personal communication).

In the videomagnetograms the existence of some intra-network bipolar features among a mixed polarity background are confirmed. Some of the bipolar features are clearly identifiable as ephemeral regions; many more have insufficient magnetic flux and are too close in scale to the resolution of the magnetograph to be able to ascertain their origin and behavior, other than to say that they spontaneously appear in the intra-network space. A typical example is the fragment F10 in the lower right of Figure 6. F10 collides with network flux and disappears. The origin of F10 is unknown. It resembles numerous other examples of very weak magnetic field fragments in the intra-network space that move directly towards and collide with network fields.

A conspicuous grouping of intra-network magnetic fields is enclosed by a polygon labelled IN in the upper left of the first magnetogram in Figure 3. These are relatively long-lived structures seen to change with time. Some of the structure appears bipolar, but it is not known whether these structures could have initially appeared and independently evolved as bipolar entities or

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whether opposite polarity fragments of separate origin have been swept together. A combination of both processes is suspected.

The time-lapse videomagnetograms also reveal a general sweeping of the intra-network fields from the interior towards the boundaries of the network cells (or the presumed boundaries of supergranule cells where the network is absent). The net convective motion, at any instant in time, results in more magnetic field from all sources (network, ephemeral regions, and intra-network fields) at the boundaries of supergranules cells than within the cells. The observed motion is generally consistent with the horizontal component of convection within supergranules (Leighton et al. 1962; Simon and Leighton 1964). However, the separation of opposite polarities of the small bipoles, as well as magnetic reconnection between adjacent intra-network fields, can result in many deviations from the average motion.

In addition to the velocity field associated with large-scale convection and designated as the 'supergranulation', Leighton et al. (1962) observed and described velocity fields having a characteristic size smaller than the supergranulation and equal or greater in scale than the white-light light granulation. They suggested a possible association between the small-scale velocity field and the white-light granulation. New observations are needed to determine if the small-scale velocity field is also associated with the intra-network magnetic fields.

Although much is yet to be learned about the dynamics of the magnetic and velocity structure of the intra-network plasma, it is clear that there is a continuous generation of magnetic field in the interiors of the network cells, and frequent destruction of opposite polarity fragments that meet near the boundaries of supergranules. It should also be noted that the videomagnetograms from Big Bear Solar Observatory do not preclude the possibility of additional generation and destruction of small-scale magnetic fields within the network.

Possibly, the intra-network magnetic fields are entirely composed of short-lived, rapidly evolving bipoles that are eventually swept to the boundaries of the supergranules. It could be the independent small-scale

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evolution of bipoles and their interactions with adjacent bipoles or other intra-network magnetic fields that yields the nonradial motions first observed on Kitt Peak magnetograms (Harvey 1983). Observations with much higher spatial resolution are needed to ascertain the true structural and evolutionary character of the most of the intra-network magnetic fields that are marginally observable with current magnetographs.

6.0 DISCUSSION

The most significant result that warrants discussion, is our repeated observation of a decrease in the line-of sight component of magnetic fields that begins when any two initially separate features of opposite polarity appear to collide. Specific features participating in the observed loss of flux are network, ephemeral regions and intra-network magnetic fields. The examples of magnetic flux disappearance illustrated in this paper are not unusual. They are representative of the many examples of magnetic flux loss seen in all of our quiet sun videomagnetograms when the exposure was sufficient to bring our the mixed polarity background due to ephemeral regions and the intra-network magnetic fields.

These new observations of the quiet sun provide a more comprehensive picture of the specific conditions under which the disappearance of magnetic flux takes place on the quiet sun than was understood from the previous research papers cited above. Several general properties and conditions of the observed disappearances of magnetic flux can be stated:

1. The disappearance of magnetic flux occurs on a small spatial scale, typically in fragments of magnetic field less than a few arc seconds in diameter.

2. The disappearance of magnetic flux is concurrent with the apparent collision of opposite polarity magnetic fields, implying that prior motion of both or either of two colliding fragments of magnetic field might be a necessary condition for magnetic flux disappearance.

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3. Close proximity of opposite polarity fields alone is not a sufficient condition for flux disappearance in the quiet sun observations.

4. The apparent loss of magnetic flux takes place gradually rather than impulsively and continues for intervals of tens of minutes to several hours until the smaller of the two colliding magnetic features completely disappears.

5. The loss of magnetic flux is clearly shared by the colliding opposite polarity magnetic fields when the magnetic field signal is not saturated on the magnetograms.

6. The disappearance of flux on the quiet sun is observed most frequently at the edges of the network or the boundaries of supergranule cells when the spatial resolution is not finer than 3 arc seconds.

When the continuity of observations has been adequate, I have seen no exceptions to conditions 1 through 4. Thus, I suspect that these same conditions exist when magnetic flux loss is observed anywhere on the sun, in both stronger and weaker fields than described here, including within active regions.

Because the videomagnetograph measures only the net flux of features resolved, the observed decreases in magnetic flux could be interpreted as an apparent effect of very small, unresolved magnetic fields merging on a scale less than the resolution of the magnetograms. Alternatively, the observed decreases can be interpreted as a real losses in the net magnetic flux resulting from a magnetic interaction such as by gradual magnetic field reconnection. Supporting evidence has not been found in favor of the hypothesis that the observed decreases could be apparent rather than real decreases. Supporting arguments for real loss magnetic flux and possible concurrent change in the magnetic field geometry are:

1. The decrease in field is consistent with the release or conversion of magnetic energy to flare energy as shown for the circumstance of flares associated with ephemeral regions in close proximity to network fields (Marsh 1978) and the circumstance of macrospicules and microflares with ephemeral

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regions (Moore et al. 1977).

2. Large-scale magnetic field patterns, on magnetograms with insufficient resolution to detect ephemeral regions, show no mixing of areas of opposite polarity as the fields diffuse over periods of months to years (see review by Howard 1978); this is indirect evidence that magnetic field is destroyed at polarity inversion zones (Mosher 1977).

3. On the videomagnetograms of the quiet sun, fragments of one polarity are not observed to emerge from network fields of opposite polarity (the converse of disappearance upon collision).

4. Magnetic reconnection or annihilation is expected from theory (Parker 1957; Petschek 1964).

For all of the above reasons, magnetic reconnection probably takes place during every disappearance of colliding magnetic fields of opposite polarity. The time-scale on which reconnection occurs may or may not correspond to the observed rate of disappearance of magnetic flux. Two possibilities are envisioned: (1) gradual reconnection and (2) explosive reconnection. Because the disappearance of magnetic flux appears to occur gradually, the more obvious possibility is that magnetic reconnection also takes place gradually and could be proportional to the forces that bring the opposite polarity fields together. If this is the real situation, it is easier to reconcile the occurrence of flares in ephemeral regions (Marsh 1978) with the dynamo theory of flares (Kan et al. 1983) than with explosive reconnection models (review by Sturrock 1980). However, the observations, at this early stage, do not rule out the possibility of explosive reconnection if the disappearance of the field is due to stresses which change the geometry of the magnetic field gradually before explosive reconnection occurs. The geometry of the magnetic field would have to change in such a way that the observed line-of-sight fields, discussed in this paper, slowly become transverse to the line-of-sight while magnetic energy is being stored that could subsequently be released by explosive reconnection. Additional observation of the total magnetic field, the line-of-sight component near the limb, and Hα images which reveal transverse structure, could help to differentiate between gradual and

explosive reconnection.

Irrespective of the precise processes involved in magnetic reconnection, the real loss of magnetic flux all over the quiet sun has far-reaching implications to our understanding of other phenomenon and physical properties also associated with the quiet sun, assuming that the lost magnetic flux is somehow converted into other forms of energy. The following paragraphs briefly suggest a few possible relationships between the disappearance of magnetic flux and its assumed conversion to kinetic, thermal, and nonthermal forms of energy which could be represented by spicules, microflares, the high temperature of the corona, and the solar wind. Since these subjects are outside of the scope of this paper, the remaining discussion is presented as briefly as possible in the context of prospective directions for future research.

Although loss of magnetic flux can be observed any time that opposite polarity fragments collide, for the observations shown, the majority of flux disappearance on the quiet sun occurs at the boundaries of the network. Spicules are also a class of frequent sporadic phenomena known to be spatially correlated with the network. Hence it seems very probable that the observed disappearances of flux might be correlated with spicules. In fact, our observations of loss of magnetic flux and speculated association of this loss with spicules have already been preceded and anticipated in various ways by Pikel'ner (1969), Uchida (1969), Moore et al. (1977), and Blake and Sturrock (1983).

On the basis of the detection of mixed polarity fields within the network by Bappu et al. (1968), both Pikel'ner (1969) and Uchida (1969) proposed that magnetic field annihilation should occur when opposite polarity magnetic fields are compressed together due the convection. Both authors developed magnetic reconnection models to explain how spicules could occur although direct observational evidence of the proposed magnetic field annihilation had not yet been seen. These models require a close temporal and spatial association between the base of spicules and the sites where magnetic field annihilation occur. This hypothesized close association has not yet been completely verified. New concurrent observations of both spicules and

intra-network magnetic fields are required to ascertain the reality of the speculated spatial and temporal occurrence of spicules precisely at the sites where we now are able to observe the disappearance of magnetic flux.

Moore et al. (1977) found that macrospicules are associated with small flares observed in association with ephemeral regions. On the basis of this finding Moore et al. (1977) hypothesized that spicules may be generated by yet smaller flares continuously occurring within the network. Blake and Sturrock (1983) have also conjectured that spicules may be small surges which also implies that spicules could be associated with microflares just as surges occur in conjunction with larger flares. Indeed, if we consider the relative sizes of surges that commonly occur with subflares and reduce the scale of typical surges to that of typical spicules, the corresponding spicule-related flares in the chromosphere would be a features having dimensions of the order of an arc second or less. Thus, it is reasonable to suspect that microflares with spicules would be difficult to detect and identify as flares. They might initially be tagged as "brightenings" or "intensity fluctuations." Spicules, although readily detectable, might be only a minor secondary effect of the occurrence of microflares in the network as implied by Moore et al. (1977) and clarified by Rabin and Moore (1980). New high resolution filtergrams and spectra of the bright features at the bases of spicules (Beckers 1968) need to be acquired to see if these features could be microflares.

To complete the argument for an association between the disappearance of magnetic flux and the hypothesized occurrence of microflares, previous evidence of the nature of magnetic field configurations and changes with flares should be considered. It has been shown many times that major flares occur most frequently when opposite polarity magnetic fields are pushed together as a result of the development of active regions growing adjacent to or within other active regions (see review by Martin 1980; Martin et al. 1982; Zirin 1983). Marsh (1978) showed that similar conditions prevail for ephemeral regions; the sites of occurrence of their flares are most often centered at the contact interface between one polarity of an ephemeral region and opposite polarity network. Since there is no reason to suspect an observable lower limit to the size of flares, it is conjectured by analogy

with larger-scale flares that the appropriate magnetic field configuration for microflares is produced when any two small opposite polarity magnetic fields are forced into contact either through the evolutionary processes of bipolar fields, motions of the network or motions of the intra-network magnetic fields.

Now that the possibility of microflare production all over the quiet sun has been reasserted as a possible consequence of our observing the disappearance of magnetic flux, other consequences of microflare production should not be ignored. One of these consequences is heating of the corona by microflares or by the process that generates microflares. Reviving the idea that spicules are closely related to the heating of the chromosphere and corona (Thomas 1948, 1950; van de Hulst 1953), Athay and Holzer (1982) show that the rise and fall of spicules can provide the thermal energy required for heating the upper chromosphere, transition zone, and possibly the corona. The study of Withbroe (1983) does not rule out this possibility although the analyses of EUV observations confirms that spicules are not a high temperature phenomenon. Rabin and Moore (1980) conclude that if spicules are produced by microflares, then spicules represent only a small fraction of heat supplied to the corona, or that of all microflares heating the corona only a small fraction may be associated with obvious spicules. The conversion of magnetic energy into energy sources for microflares and associated effects, which could heat the corona, is a subject which deserves further quantitative analysis.

By analogy with larger flares, another conjectured consequence of microflares on the quiet sun is the acceleration of ionized particles, the continuous acceleration of particles from the whole sun. Where the magnetic fields are closed in the corona, the accelerated particles in general would not escape and would contribute to regions of enhanced coronal density; where the coronal magnetic fields are open, such as in coronal holes, the ionized particles associated with microflares and accelerated outward could be synonymous with an appreciable fraction of the solar wind.

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Other observations indicating magnetic flux emergence and magnetic reconnection as the source for the solar wind are reviewed by Pneuman (1983) as support for his solar wind model based on small-scale magnetic reconnection. Alternate particle acceleration mechanisms which could be applicable to the solar wind are discussed in the dynamo theory of solar flares by Kan et al. (1983) and in earlier flare models (review by Sturrock 1980).

The mechanisms by which magnetic energy can be converted into kinetic, thermal, and nonthermal energy are not yet completely understood. It is hoped that these observations on the dynamics and disappearance of small scale magnetic flux fragments will stimulate renewed consideration on how both gradual and rapid magnetic field reconnection takes place and what the primary and secondary effects of reconnection could be in the solar atmosphere.

7.0 SUMMARY

1. The merging and separating of small fragments of network magnetic fields of the same polarity were measured in the range of .1 to .5 km/sec. The motions occur along the boundaries of network cells and, in some cases, have provided an indirect but clear measure of the birth and growth of supergranule cells.

2. The opposite polarities of ephemeral regions are consistently observed to separate from each other as a function of time except when the poles of the ephemeral region develop or move within a few arc seconds of adjacent magnetic fields of comparable or greater flux. If an ephemeral region has reached its maximum flux and its motion is not inhibited by adjacent fields, a gap develops between the opposite polarities as they continue to separate from each other.

3. Previous observations are confirmed (Livingston and Harvey 1975) showing that intra-network magnetic fields spontaneously appear in the interior of network cells and generally move towards the boundaries of the cells with frequent exceptions to radial motion. The Big Bear

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videomagnetograms, like the Kitt Peak magnetograms, reveal that at least some intra-network magnetic fields originate as tiny bipoles. The amount of mixed polarity field increases with improved atmospheric image quality and the spatial resolution of the magnetograms.

4. The described motions of the network, ephemeral regions and intra-network magnetic fields result in the intermingling and interacting of the magnetic fields from all of these sources. Similar polarities are observed to merge without obvious change in the net flux. Opposite magnetic polarities from separate sources often collide and coincident gradual loss of magnetic flux is observed in both colliding fragments until the smaller fragment disappears.

5. The collision and disappearance of opposite polarity fields takes place on a small spatial scale and is observed most frequently at the border of the network cells because of the influence of the bulk motion of convection on the quiet sun magnetic fields. Small new bipolar fields, however, often show motion that appears to be initially independent of the general pattern of convective motion.

6. The disappearance of magnetic flux on the quiet sun is speculated to be a consequence of a magnetic interaction, such as magnetic reconnection, and is suggested to be the energy source for microflares and spicules in concurrence with the hypotheses of Moore et al. (1977).

7. In coronal holes, the disappearance of magnetic flux is also suggested to be related to the solar wind through either gradual or impulsive reconnection in agreement with the basic assumption of the Pneuman model (1983).

8. The dissipation of the energy released during frequent small-scale magnetic reconnections over the whole sun could heat the corona; possibly through the occurrence of microflares, as stated by Rabin and Moore (1980), which should be more effective in heating the corona than spicules.

Acknowledgments

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Fig. 1.--Videomagnetograms of this area of the quiet sun must obviously show the the network magnetic fields. Increased numbers of ephemeral regions and the existence of intra-network magnetic fields are revealed as the exposures are increased by a factor of 2 in the following order: upper left, lower left, upper right, lower right. Following the date and universal time, the last two numbers in the upper right give the exposure time in seconds (including any interruptions) and the number of 'integrations,' which is equivalent to the number of scans of the whole field by the television camera in recording either polarity of the magnetic field. The concentric contours in long exposure magnetograms are areas where the magnetic field has reached saturation, and are not reversals of the polarity of the magnetic field at these locations.

Fig. 2.--These videomagnetograms show motions of small scale magnetic field fragments in an area of negative network on 1983 March 31. Network fragments that are splitting apart from larger network fragments are labelled S1 (middle of each frame) and S2 (upper right). Network fragments that move toward and join other network fragments are labelled J1 and J2 (upper left). An expanding network cell, C1 (lower left), is accompanied by continuous splitting apart and joining of network fragments along its boundary. The birth of a new network cell, C2, is obvious by 22 52 10 UT from similar motions of network fragments outlining the new cell.

Fig. 3.--Long-exposure (67 sec ave.; 1024 integrations) videomagnetograms on 1983 June 28 reveal the birth or development of four ephemeral regions, E1, E2, E3, and E4, whose sites are marked by an oval. As each bipole increases in total flux and area, the centroids of their opposite polarity fields gradually separate as a function of time. If the ephemeral regions do not occur abutted against adjacent strong magnetic fields, the separation of the opposite polarities continues and a gap between the opposite polarity fields

becomes apparent when the fields are beginning to decay.

Fig. 4.--Videomagnetograms on 1983 July 1 show the birth of bipolar ephemeral active regions relative to network magnetic fields. Ephemeral region E5 is born in the middle of a network cell (19 03 02, lower left frame). Ephemeral regions E6 and E7 are born on the boundary of the network cell seen in the middle of the frames (21 30 13 UT). Such small ephemeral regions appear to have no preferential sites of birth and no preferential orientation with respect to the network cells. However, note that only E5, in the middle of a network cell, shows appreciable separation of its opposite polarity fields as a function of time while E6 and E7, on or near the boundary of the stronger network fields, show little or no motion of their opposite poles.

Fig. 5.--Fragments of magnetic field on an area of the quiet sun are identified on the upper middle image. Negative field fragment F1 breaks away from a more stationary source fragment, moves eastward, and collides with positive field fragment F2 which is moving southward. The disappearance of magnetic flux in both F1 and F2 is coincident with their coming into apparent contact. In the center, positive field fragment F3 shows curvilinear motion. After F3 breaks away from the positive field network clump to the north, it passes negative clump F4 and curves towards F5. In the upper right of each image positive field fragment F6 and negative field fragment F7 slowly approach each other. Upon apparent contact, their relative motion does not cease although their magnetic flux is decreasing. F6 and F7 slide past each other giving the illusion of a stationary rotating bipole before the negative fragment completely disappears.

Fig. 6.--In the upper left of the images, the positive polarity of ephemeral region E8 slowly disappears after coming into contact with nearby negative polarity network. In contrast, ephemeral region E9 decays before either of its separating poles collides or merges with network. In the center of the images, positive field fragment F8 (19 03 11) remains stationary until it is bumped by negative fragment F9, whereupon F8 and F9 concurrently lose flux
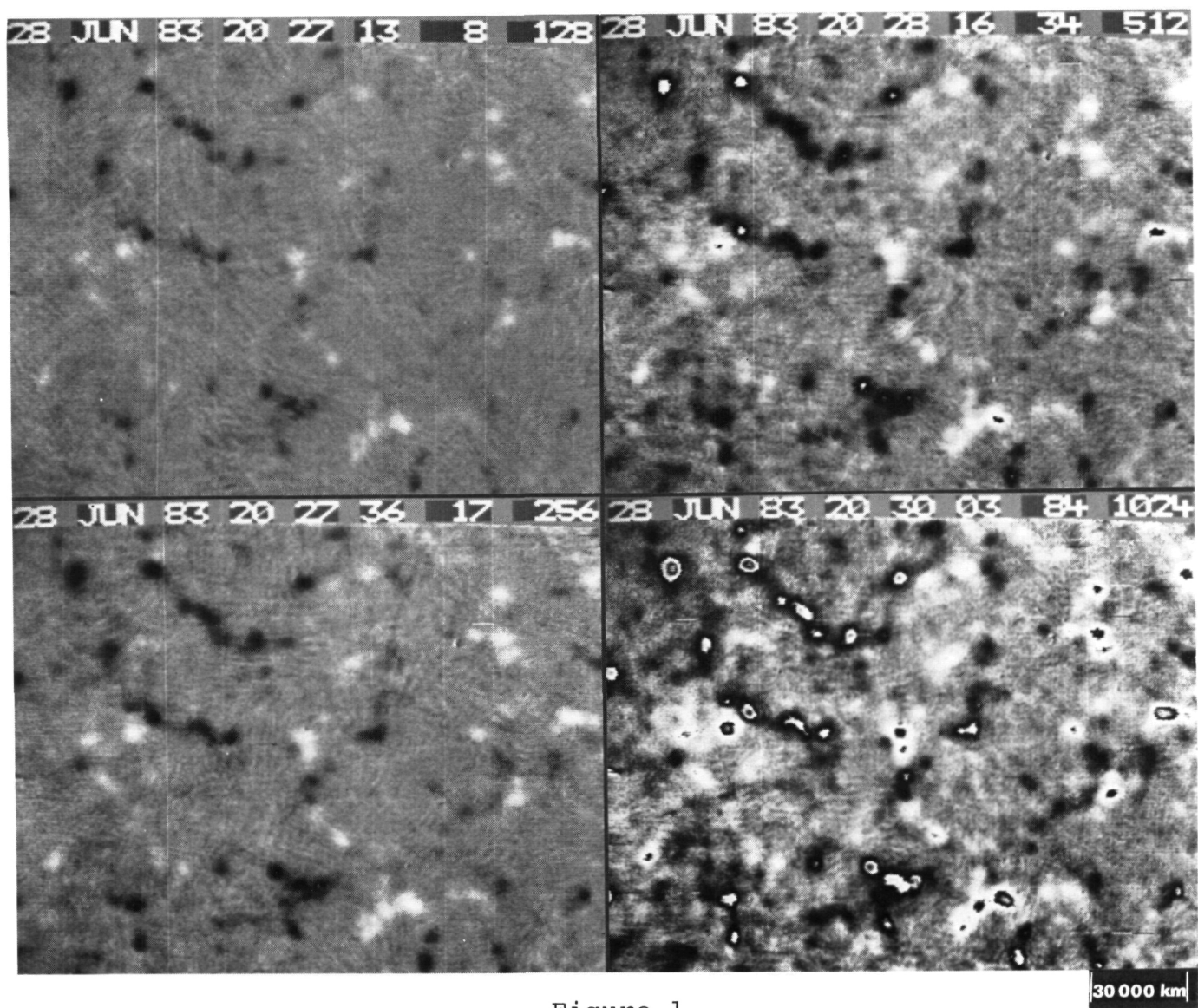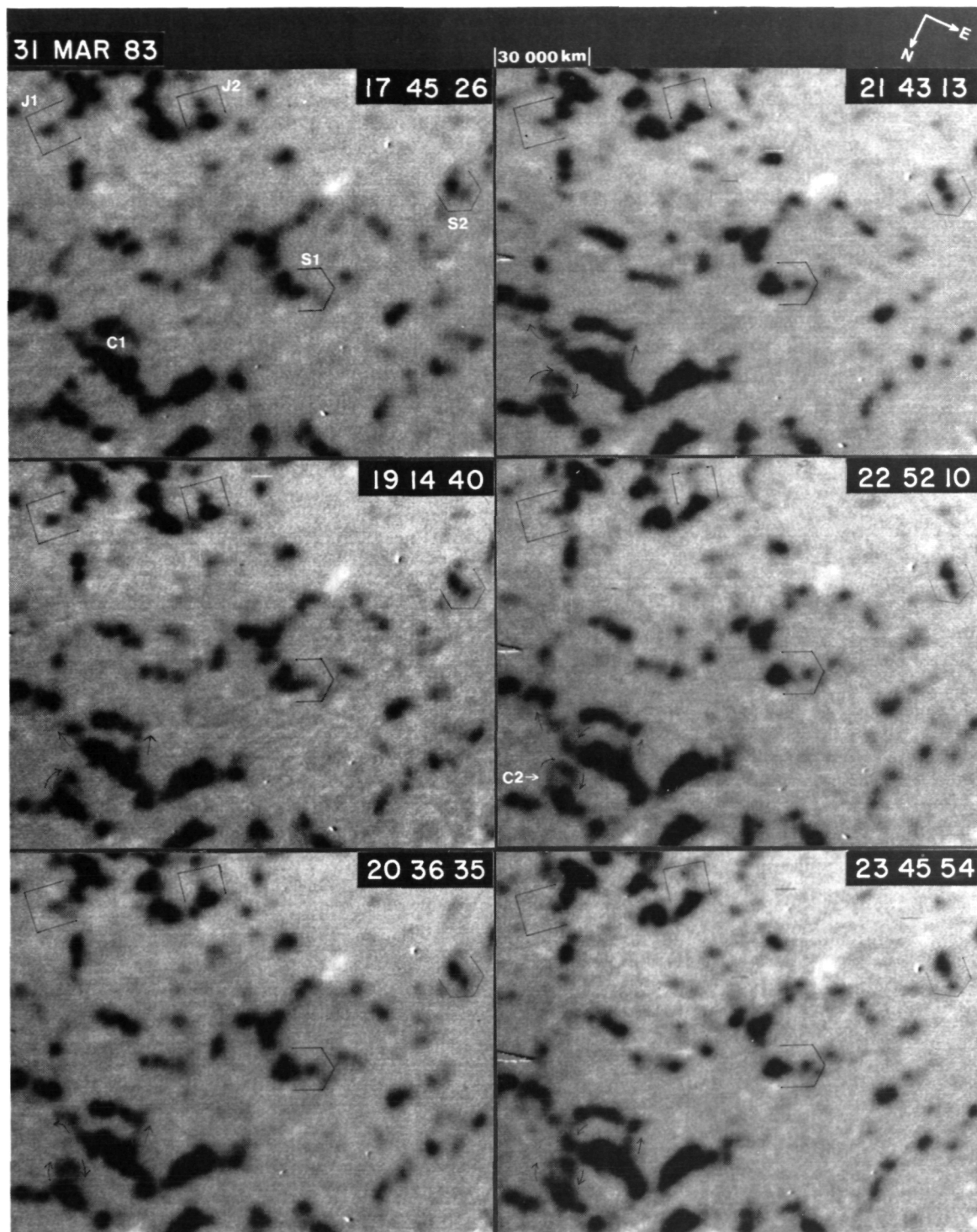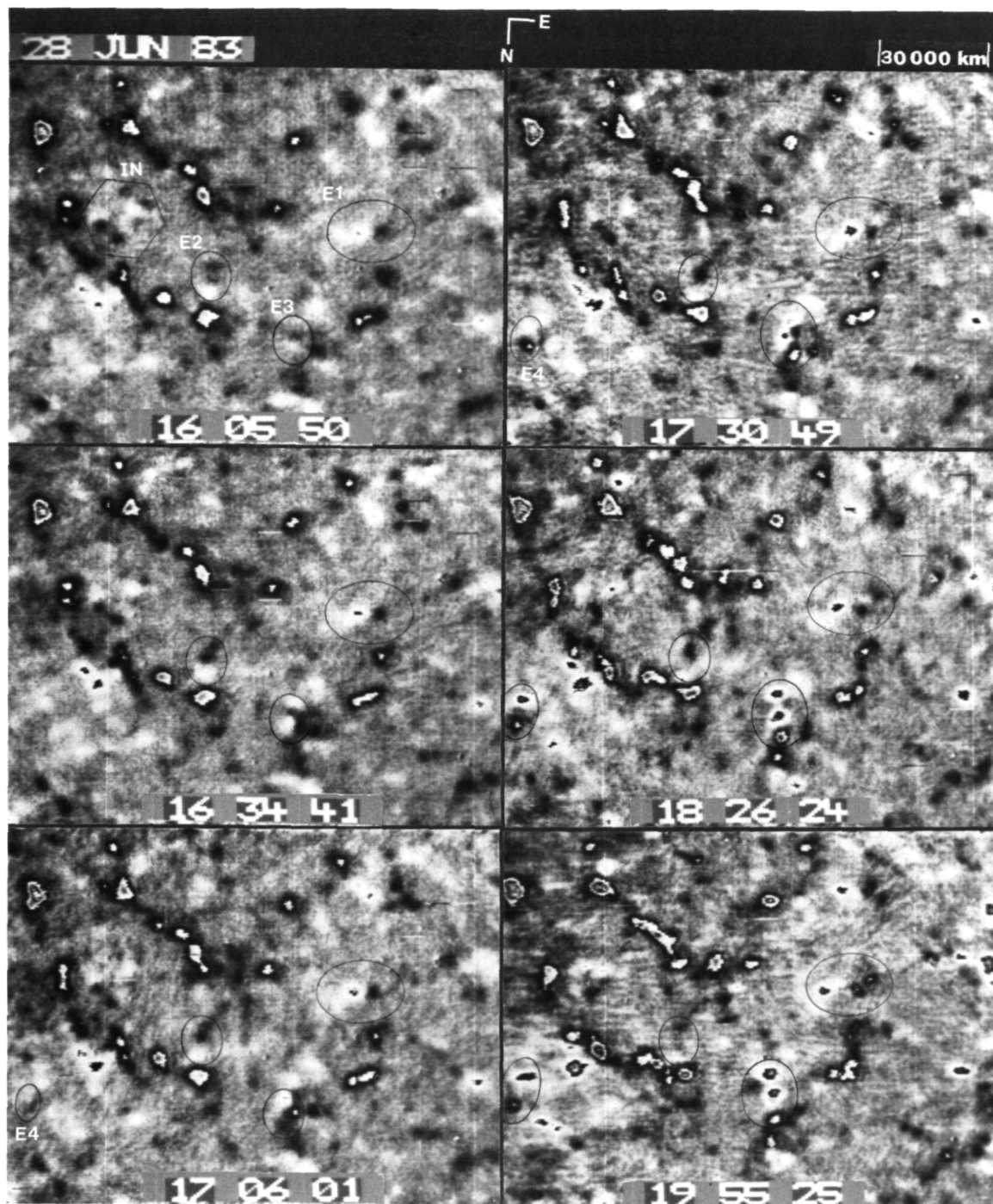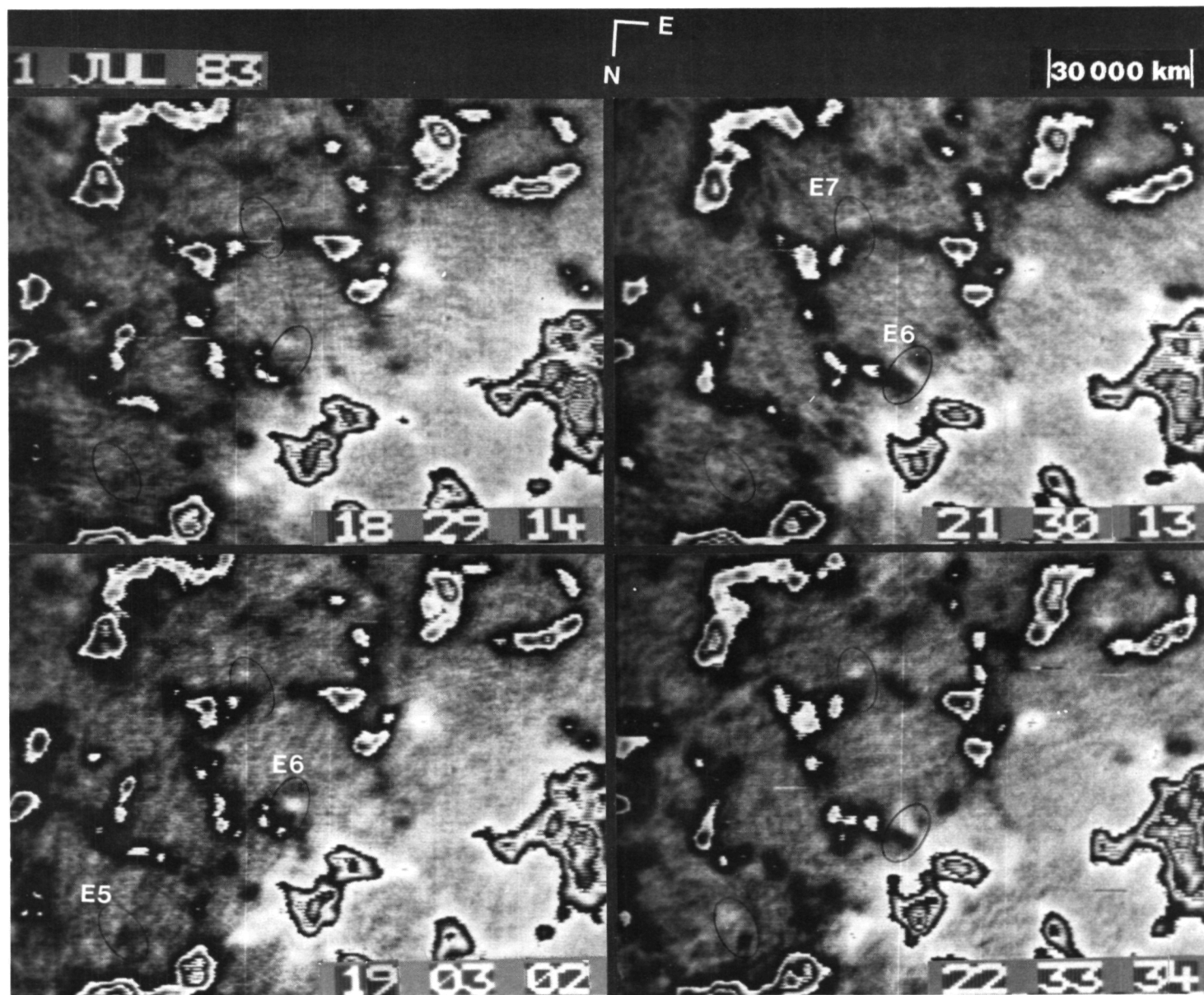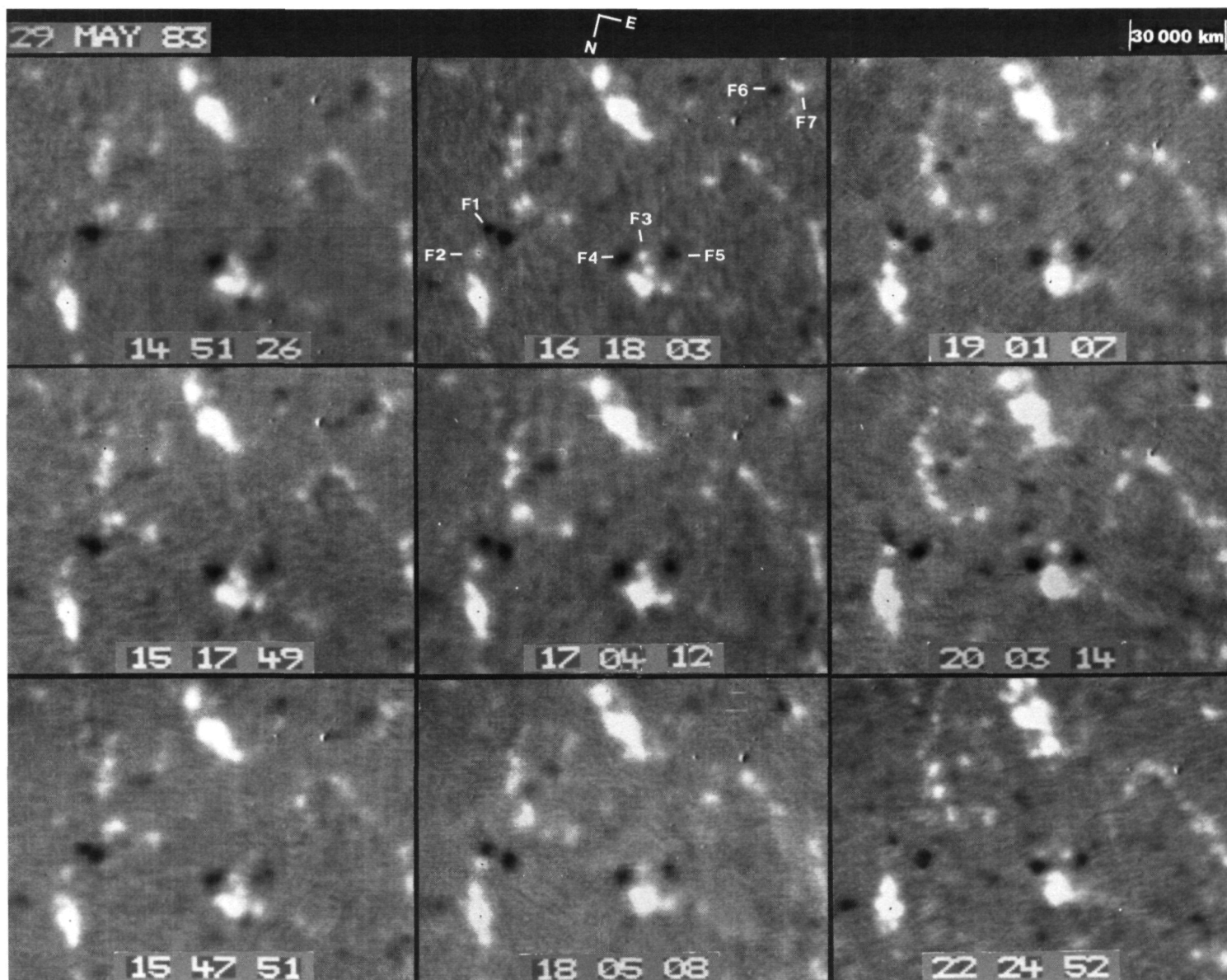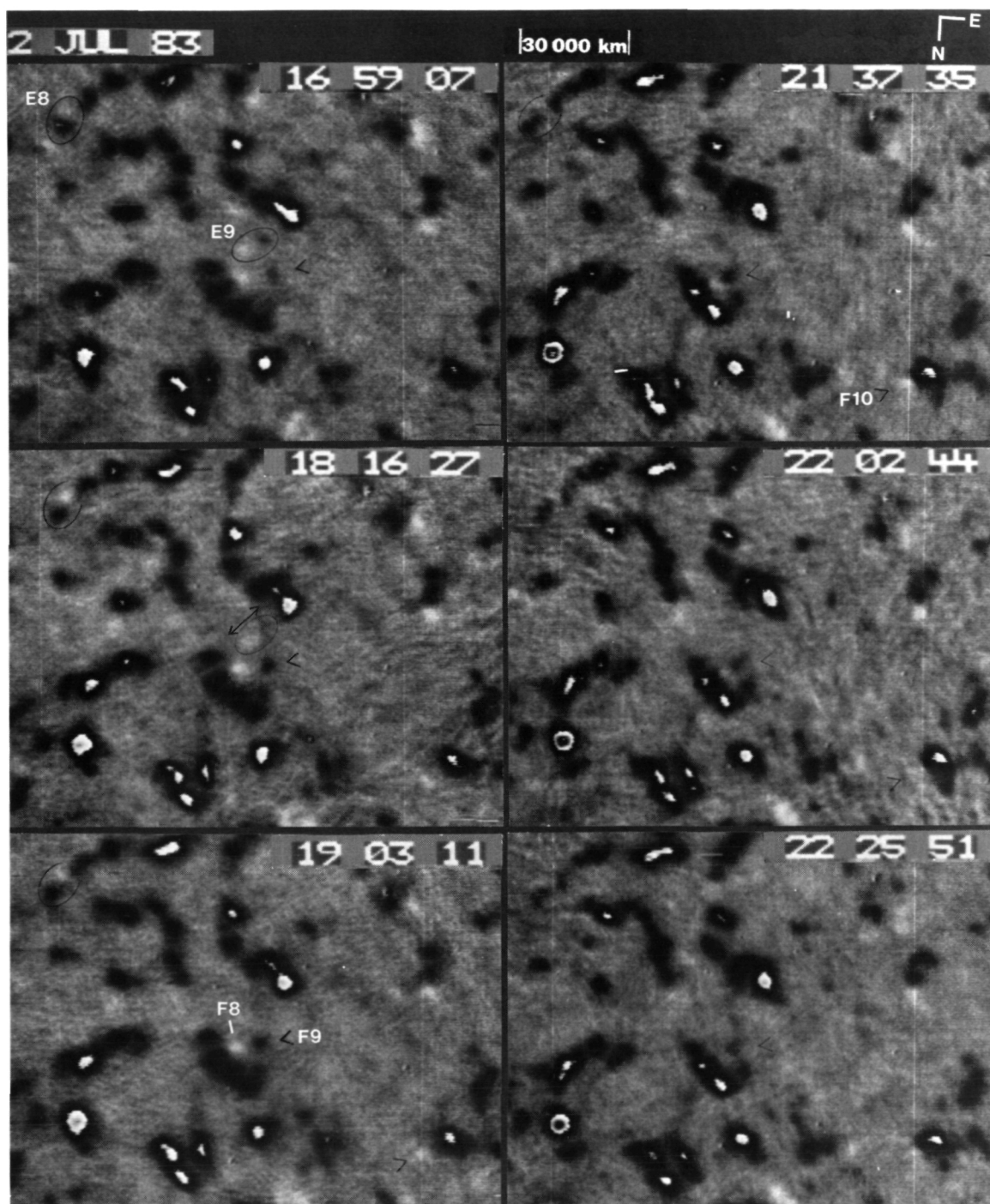
Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

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